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Budd Co, Fort Washington, PA Technical Center

Prepared for

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April 1979

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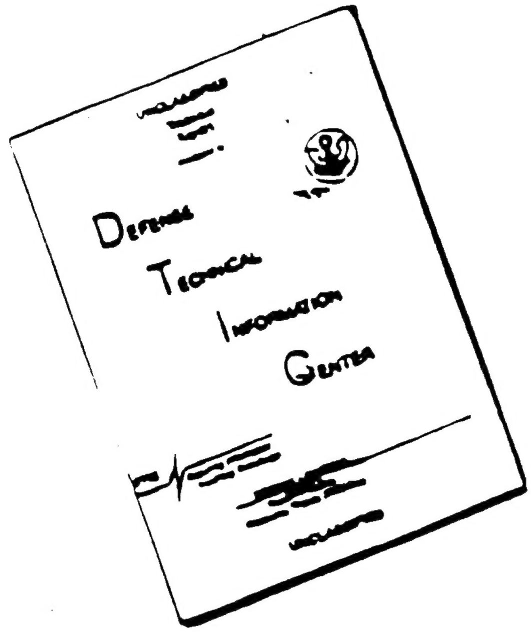

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MATERIAL APPLICATIONS IN FUTURE AUTOMOTIVE STRUCTURE
Volume I: Summary Report

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16. Abstract

Candidate materials which might be used in future automotive structure were selected. These included steels, aluminum alloys plastics and fiber reinforced composites. General materials property data, availability, manufacturability, cost and their effects on crashworthiness, durability and non damageability were evaluated. Three vehicle structures; body on frame, unibody and unibody van were investigated with the possible use of the candidate materials in mind. Finite element analysis and mass-spring modeling of the vehicle structures were completed to determine limits and boundaries of materials application. The existing structure with appropriate sectional properties were obtained from current production vehicles. New concepts were suggested using the candidate materials in several forms. Advantages, disadvantages, manufacturing costs and the general complexity of alternate applications were reviewed. Suggested typical weight savings which might evolve through the use of these materials were presented.

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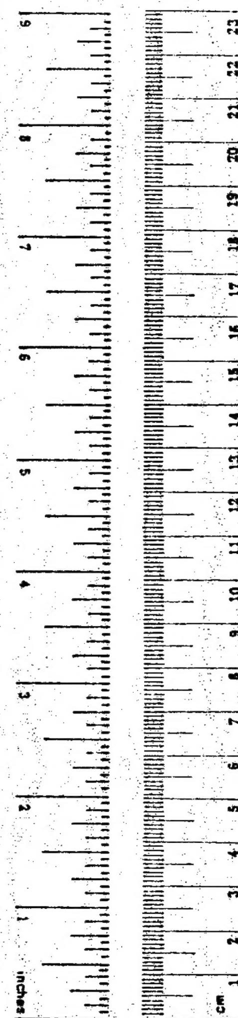
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

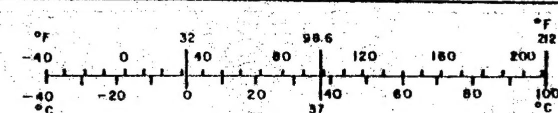
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The assistance and contributions of Budd Company engineering personnel; Richard Freeman, William Kesack, Paul Kirsch and Les Solymosi toward the completion of this program is acknowledged.

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1.0 INTRODUCTION

The 1970's has witnessed an intensified world-wide interest in materials and energy conservation. A number of recent social and economic factors have stimulated studies by industry, institutions and the Federal Government. Conclusions reached, based on these studies, generally agree that there are serious shortages of energy and of some materials. The primary forcing issue for a materials change is the dependence of fuel economy on vehicle weight, Figure 1, and the ability to reduce weight with alternate materials.

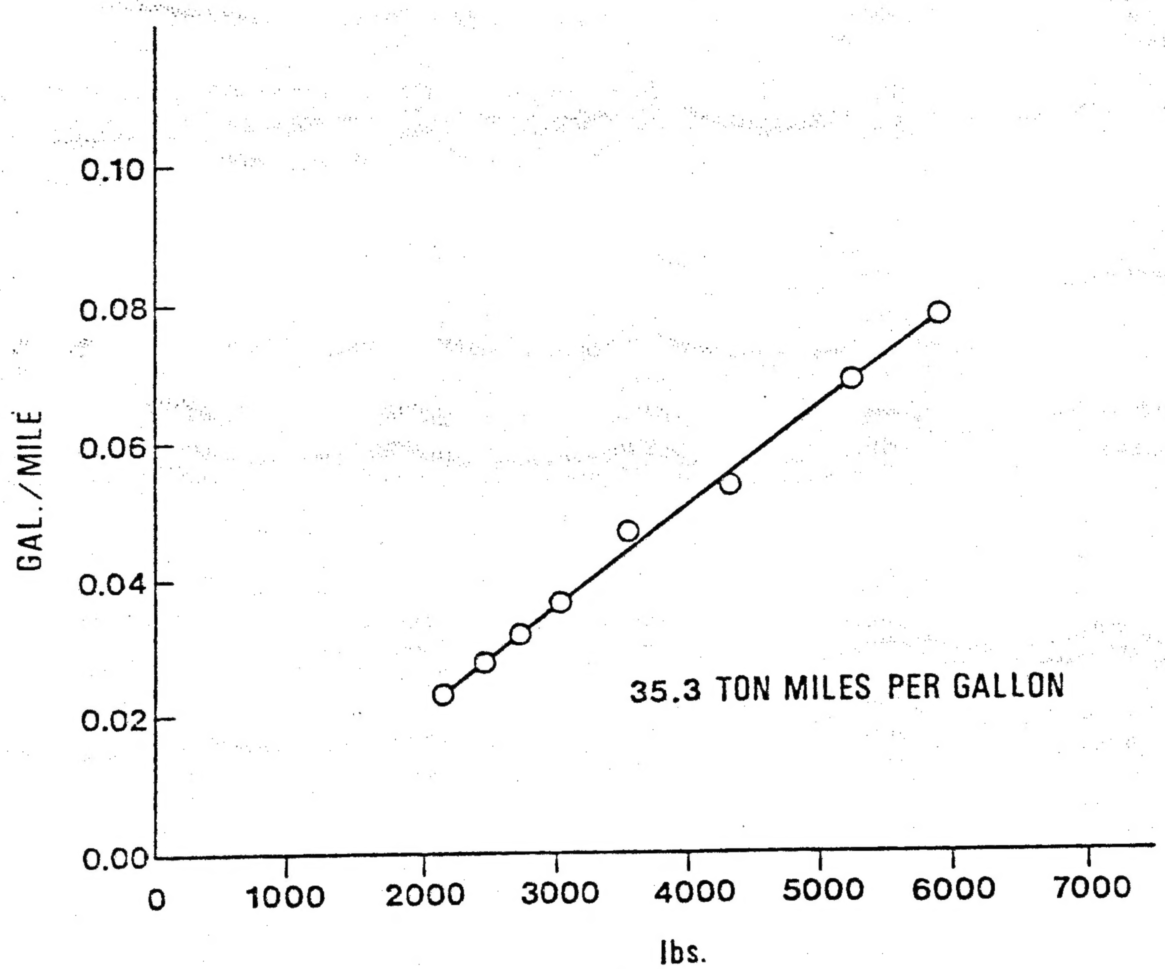
With these projected shortages it appears probable that changes will occur in the materials used in future automotive structure. This report is a summary of a study which was directed toward determining in part what materials might be used, what are the forcing issues to change, and what would be some of the effects.

This study effort was directed toward a number of subjects which included.

1. Candidate material selection
2. Materials availability and costs
3. Arear of application in the vehicle and weight reduction
4. Manufacturing processes and cost
5. Durability, crashworthiness and damageability
6. Vehicle disposability and recyclability

The structural characteristics, manufacturing processes, crashworthiness and damageability were reviewed for a body on frame, front wheel drive unibody and a unibody van. Weight reduction possibilities and the general effects on cost were examined. Design concepts were developed to illustrate material applications and the associated complexities.

FIGURE 1 1977-AUTOMOBILE FUEL CONSUMPTION VERSUS WEIGHT



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2.0 CANDIDATE MATERIALS

Current automobile structure is fabricated primarily from low carbon steel sheet (AISI 1008-1015 equivalent). A large number of relatively new materials have been suggested by materials suppliers and are under investigation by the automotive industry for weight reduction possibilities.

A candidate material for future structure must possess mechanical and physical properties and resistance to the environment, if not equal to, then at least competitive with low carbon steel in a new structural concept. A review of strength, stiffness, density, corrosion resistance and associated properties of a wide range of materials was completed.

The ores or sources of the materials must also be in sufficient abundance in the Earth's crust to supply large quantities for many years. A number of references were reviewed including production data from the Bureau of Mines to obtain an overall view of material consumption. The automobile industry consumes vast quantities of materials and requires an uninterrupted supply.

Available materials selected on a basis of properties must also be capable of being shaped, joined and otherwise processed into a final vehicle at a high rate and at a marketable cost.

Materials selected as candidates for future automotive structure, based upon the above factors are covered by the following general groups:

1. Low carbon steel
2. High strength low alloy (HSLA) steel
3. Aluminum alloys
4. Magnesium alloys
5. Glass, carbon and organic fiber composites
6. Elastomeric and unreinforced plastics
7. Laminates; metal skins, plastic core

Within these seven groups are many metal alloys capable of being heat treated and numerous formulations of reinforced plastic matrices which develop a wide range of properties for use by the design engineer. This abundance of materials is in itself part of the problem designers face in the selection process since individually they may not be well enough defined to make a difinitive choice.

3.0 MATERIAL AVAILABILITY

The natural occuring sources of the elements comprising the selected materials can be divided into two groups; geochemically abundant and geochemically scarce, Table 1. Iron, aluminum, silicon, oxygen, magnesium, manganese and hydrocarbons are considered abundant. That is, they make up a sufficiently large proportion of the Earth's crust that they do not necessarily have to be concentrated naturally to be economically extracted. Other elements such as titanium, nickel, chromium, copper and molybdenum are not as abundant, must be concentrated by natural means, and are in danger of being depleted world wide in the near future.

At present the United States does import large quantities of the ores of some of the above elements.

Iron ore, bauxite (for aluminum) and petroleum (for hydrocarbons) are imported in large quantities. These imports are primarily economic and will be expected to be continued unless the price of the imported material exceeds domestic prices or nationalistic moves cut off supplies. Aluminum can be extracted from ores other than bauxite but at a higher cost. These other ores, aluminum clays, exist within the United States in hugh quantities. Hydrocarbons in the form of coal, natural gases, shale oils and renewable sources exist domestically in sufficient quantity to supply most of the plastics feedstocks. They are not used however since the cost of by-products from petroleum refining is still lower.

Refined metals, reinforcements and organic matrices must be converted or supplied in mill forms for the manufacturer to convert into automotive components. The capital costs and investment risks are great in the construction of such mills. For this reason mill capacity has been, is and will remain marginal; on a fairly strict supply and demand basis.

The increases potential of environmental disruptions due to the larger quantities of materials being processed and the advent of new and unknown chemicals increases the needs for regulation or control of the process and wastes. This in turn leads to higher capitalization and maintenance costs in existing facilities as well as the new and unbuilt facilities.

TABLE 1: METALLIC ELEMENTS IN CONTINENTAL CRUST

Geochemically Abundant Elements	Weight Percent
Silicon	27.20
Aluminum	8.00
Iron	5.80
Calcium	5.06
Magnesium	2.77
Sodium	2.32
Potassium	1.68
Titanium	0.86
Manganese	0.10
Geochemically Scarce	**Weight Percent**
Copper	0.0058
Gold	0.0000002
Lead	0.0010
Mercury	0.0000002
Molybdenum	0.00012
Nickel	0.0072
Niobium	0.0020
Platinum	0.0000005
Silver	0.0000008
Tantatum	0.00024
Thorium	0.00058
Tin	0.00015
Tungsten	0.00010
Uranium	0.00016

Reference: 1

4.0 AREAS OF APPLICATION

The majority of the automotive structural components, body-in-white, can be considered as beams, single wall panels and double wall panels. The body-in-white consists of the passenger compartment, doors, hood and deck lid, front fenders and frame. Unibody construction does not have a separate frame and obtains the necessary stiffness by heavy reinforcing sills, integrally welded with sheet metal parts into the structure. The front and rear bumpers (low-speed energy management systems) consist of beams and either hydraulic or elastomeric stroking devices.

The design criteria of automotive structure is primarily stiffness, or minimum deflection, although the tensile strength and fatigue strength allowables must not be exceeded. Equal stiffness for minimum weight in beams, sills and double wall panels can be compared for various materials by calculating the ratio of their elastic modulii to density. In this instance steels are superior or equal to the other metals and are exceeded only by carbon or aramid fiber reinforced composites.

When equal stiffness for minimum weight is compared in single wall panels then thickness becomes the more important factor. Low carbon steel is poor compared to the other materials in this type of application, and carbon fiber composites and aluminum alloys should be superior. In panel applications, dent resistance is also desireable, and higher strength can be traded for thickness. HSLA steels are superior to low carbon steel in this respect and may result in increasing applications in exterior body panels at a reduced weight. New developments in aluminum alloys have increased their competitiveness in dent resistance applications.

Exterior panels such as fenders, outer door skins and the lower portions of quarter panels may in some instances provide no real benefit to the vehicle structure. In these cases plastics materials of relatively low strength and stiffness can be utilized. Glass reinforced polyester (SMC, BMC) have been used successfully in some applications. Elastomeric grade materials, with and without reinforcements, offer considerable potential for weight reduction in future automobiles at a minimum cost increase.

Front and rear management systems have traditionally used a stiff bumper beam. Elastomeric foams of moderate density have excellent energy management characteristics and the potential to replace bumper beams at a reduced weight.

5.0 MANUFACTURING PROCESSES

While the engineer - designer may be capable of developing the lightest, most efficient design from a particular combination of materials or geometric shapes, this does not insure that the part or components can be made or assembled into a marketable vehicle. Low carbon steel possesses a combination of basic properties which makes it readily manufacturable and this factor together with a sixty year experience background establishes a baseline for the comparison of other materials. While there may now be a resistance in manufacturing areas to new materials it is expected that this would disappear after a few years.

There are certain basic limitations or characteristics which exist in the manufacturing of each material. In the area of joining, for example, aluminum alloys cannot be welded to steels directly. Joints must be made with a transition metal, by adhesive bonding or by mechanical fastening. Plastics and reinforced composites will also require adhesive bonding or mechanical fastening. These processes are slower and more expensive than the resistance spot welding of low carbon steel.

There are also existing limitations in the thickness, width or length of a mill product, of a sheet metal stamping or of a molding which can be produced. These limitations will not permit an engineer - designer to take full advantage of a material characteristic and should be recognized.

Many of the excellent characteristics of low carbon steel are not considered until attempts to produce the same component from another material are evaluated. The excellent formability and ease of obtaining high quality finishes are not easily achieved in other materials.

With the introduction of aluminum alloys, plastics and reinforced composites new capitalization is required. Aluminum alloys require additional cleaning facilities and welding equipment. Plastics and composites require new presses or molding equipment and possibly alternate paint systems.

The direct labor cost is expected to increase with the introduction of the alternate materials. This additional cost will be high initially and gradually decline but will never be as low as for the steels.

New processes are being developed to reduce the direct labor cost. An excellent example is in the RIM process where reaction (R) between two or more components occurs after they are mixed and injected (I) in the mold (M). Techniques appear feasible to develop highly automated, low labor cost systems. This process will mold elastomeric components for the near structural applications such as fenders.

6.0 DURABILITY, CRASHWORTHINESS AND DAMAGEABILITY

The automobile is a relatively complex structure requiring considerable analysis and extensive testing. Even with the large amount of reliability testing, failures occur in service when subjected to a diverse set of operating conditions.

Introduction of new materials, modified designs and new manufacturing and assembly processes increases the potential of service failures. Analysis of the structure can indicate adequacy yet there is insufficient information on the alternate materials and how they will withstand the operating environment.

A considerable number of experiments are being conducted by the automotive industry to evaluate materials in various components. Actual service time is accumulating with generally satisfactory results. As the methods of analysis improve, a knowledge of service loads increase and actual service experience builds, it is believed that durability and safety will be satisfactory with the alternate materials. The effect of long time cyclic loading and exposure to corroding and degrading environments may require several years to complete the evaluation.

A 1977 Chevrolet Impala, a 1977 Volkswagen Rabbit and a 1977 Dodge Sportswagon were disassembled and the structure reviewed and analyzed. Sufficient drawings were made and section properties determined to prepare a finite element model, Figure 2, for each vehicle. Deflections and stresses were then determined for static loading conditions representing extremes of service. Analysis was also completed for the cases of aluminum alloy replacement of the steel on a gage for gage basis.

Concepts were developed to illustrate how structure might look if each of the vehicles were made from fiber reinforced composites and as composites of steel and aluminum alloy sheet metal stampings.

A wide combination of alternate material applications can be made with varying levels of weight reduction and complexity of manufacturing. The simplest approaches appear to be; make the passenger compartment (and frame) from steel and all of the bolt on items from alternate materials as desired. A second approach would be to make the entire vehicle out of the material desired. The third approach is to make a steel space framework and attach panels of alternate materials to this cage of steel.

Crashworthiness of the two automotive structure types, body on frame and unibody, were evaluated using a mass model, Figure 3, and comparison with actual dar-to-barrier test data. Limited testing was also conducted on rectangular section columns made of several representative materials in a drop tower facility.

FIGURE 2 FINITE ELEMENT MODEL, VOLKSWAGEN RABBIT

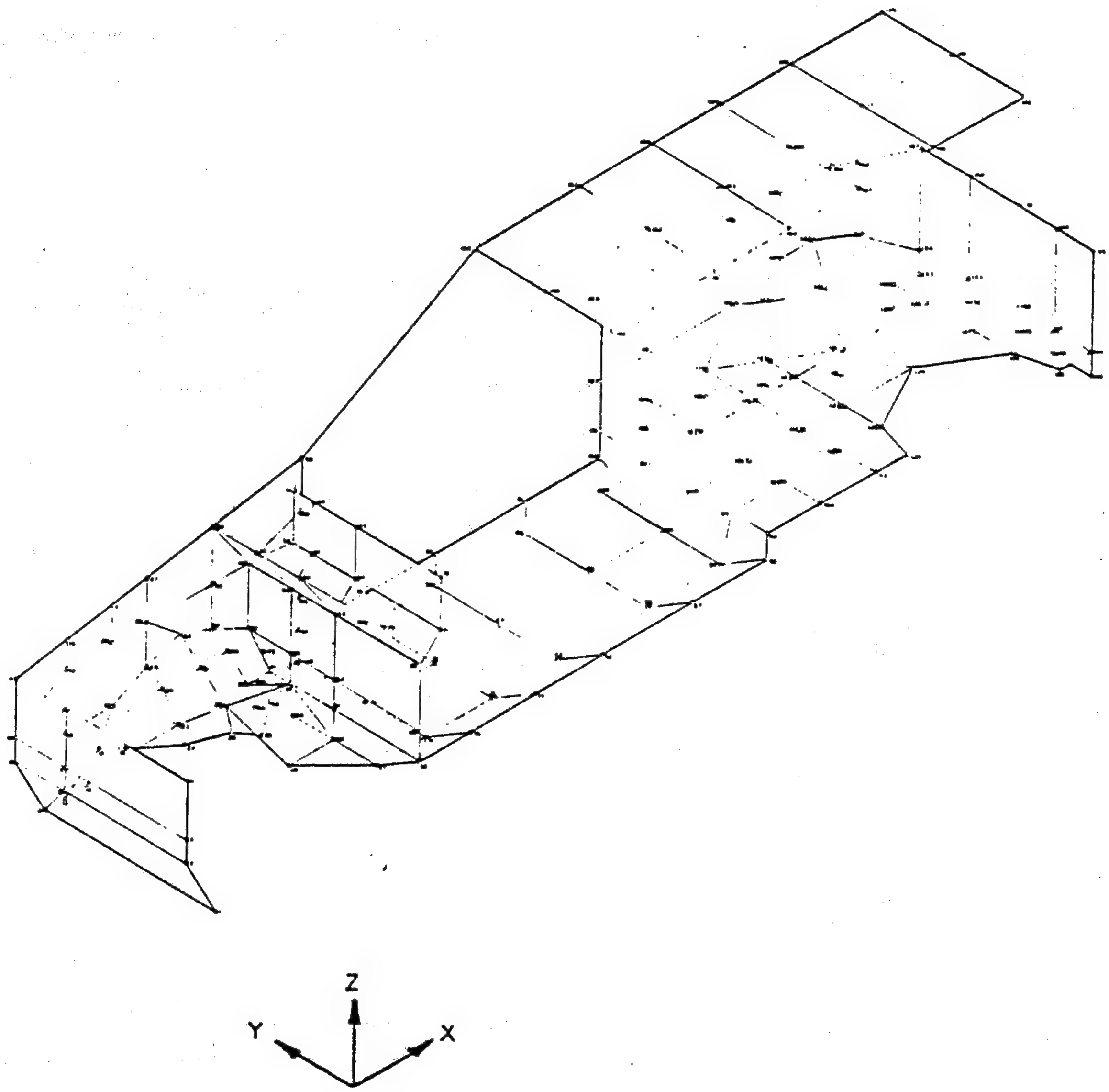
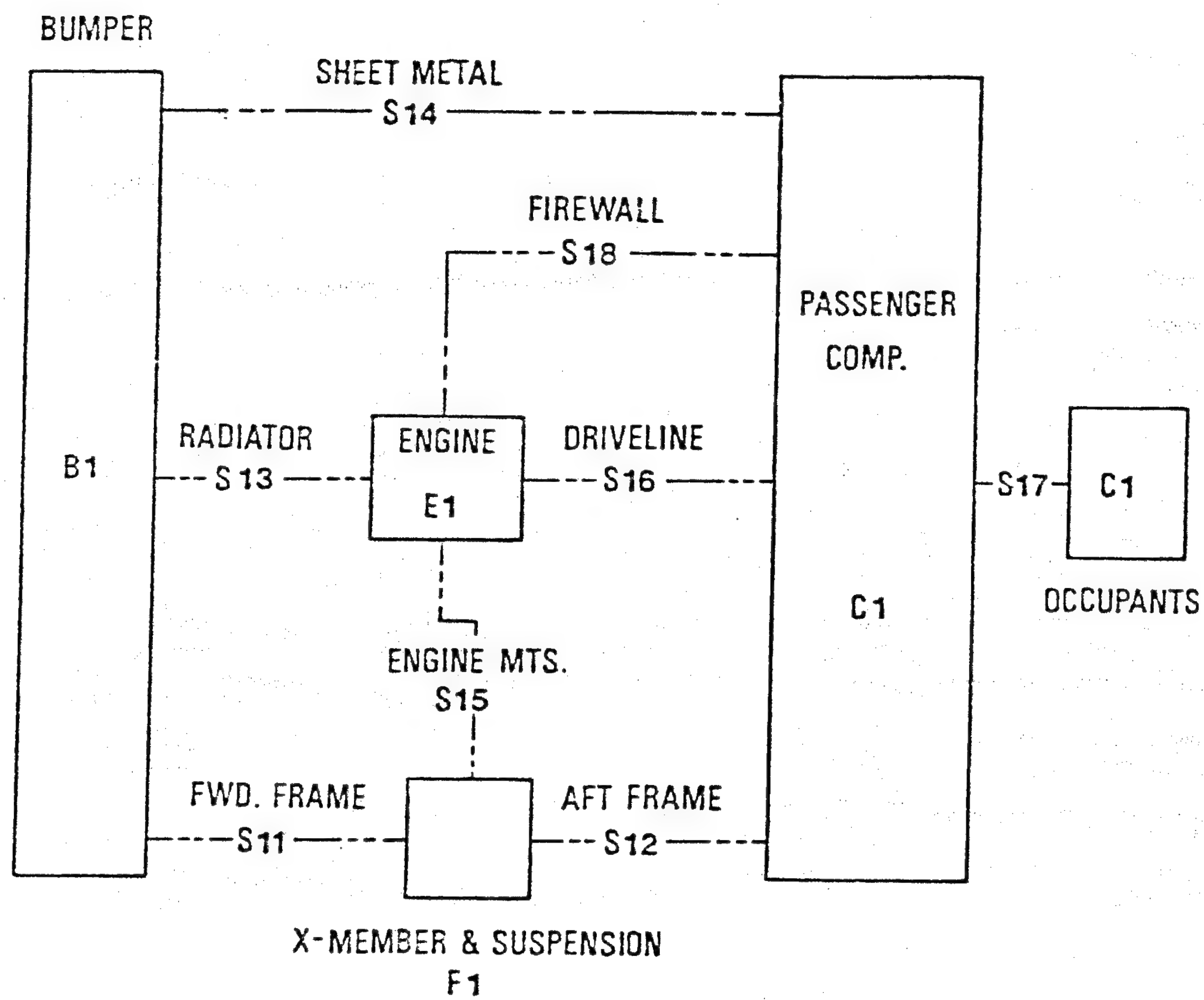


FIGURE 3 BARRIER CRASHWORTHINESS MODEL



Analysis of the car-to-barrier test data indicated some possible improvements which would improve the crash pulse, theoretically. These modifications were examined and weight penalties or reductions which might be obtained using various steels and aluminum alloys. Using data from the drop tower tests the structure could be modified with a weight reduction and still improve the crash pulse.

Based on the drop tower testing it was concluded that the alternate materials applications could reduce weight and probably result in improved crashworthiness.

Care must be observed however in the design process. It is entirely possible to develop a very soft or very aggressive vehicle if crashworthiness is not considered in the design for other criteria such as stiffness or durability.

New elastomeric materials, as moderate density foams, were evaluated for possible use in non-damageable front and rear energy management systems to replace existing bumpers on the Rabbit and Impala. A minimum of testing was conducted at impact speeds up to 18 mph to establish that no abnormal strain rate effect existed. The analysis of stroking distances, energy attenuation and accelerations for the foam energy absorbers indicated the possibility of 15 mph non-damageable systems at reduced weights.

7.0 DISPOSABILITY AND RECYCLABILITY

Recycling of worn out or disabled vehicles is suggested as a means of reducing energy consumption and as a means of material conservation. Currently a system of recycling and essentially all steel automobiles is in effect. The process is marginally cost effective and historically is cyclic. There are periods of high scrap value when discarded vehicles are in demand and then succeeding periods of low scrap value when tax dollars are needed to remove automobiles from the streets.

The future is unpredictable but based on a declining reserve of energy, vehicles should be designed with recycling in mind. Hang on items which can be readily identified and removed with a minimum of labor can be made from a single material or compatible materials.

8.0 SUMMARY

Candidate Materials

During the course of this investigation a most probable list of alternate candidate materials for future automotive structure has been examined. These materials were considered as groups of materials rather than individual compositions, such as: aluminum alloys and not 6061-T6. In some instances attention had to be focused on a particular alloy or composite formulation to show an effect or to report data.

Availability

A number of references were reviewed to determine if the raw ore or crude oil were available to provide the necessary quantities of mill product. The candidate materials selected were steels, plastics, aluminum alloys and fiber reinforced composites. Since the primary components of these candidate materials are iron, aluminum, silicon, oxygen and hydrocarbons and these components are the major constituents of the Earth's crust, it was concluded that there is no lack of raw materials. As the ore or crude hydrocarbons become less accessible, however, the energy and dollar cost of procurement will increase. Those materials requiring the least effort to obtain will be consumed first. To conserve energy, materials and possibly cost, conservation measures should be promoted at every instance. As an example, the use of alternate materials in automotive structure should be selected with the intent to recycle.

Mill Capacity

Refinery and mill capacity is marginal and will remain that way. The suppliers of ingot, bar or sheet will not provide capacity much greater than the current demand. New refinerys and mills require very large capital costs. Aluminum primary refining requires tremendous quantities of energy to reduce the oxides and the industry is in direct competition with all other business and residential demands on the supply of electric power. This one factor reduces the potential of aluminum applications in automotive structure.

Vehicle Designs

Passenger vehicles and light duty trucks and vans are currently body-on-frame or unibody construction. The candidate alternate materials can be used for all the components required to construct these structures, but each material has its advantages or disadvantages when compared to one another. The design criteria, material properties and packaging restraints must be reviewed for each case. Prior to a final material selection the safety, crashworthiness and durability in a service environment must also be considered. Manufacturing feasibility, material availability in the form desired and a detailed cost analysis must then be completed to obtain a true evaluation of all materials. The material selection process is complex and may require several iterations before the process is complete.

State of the Art

Many alternate materials are currently being evaluated by the material suppliers, component suppliers to the automotive industry and the automobile producers themselves. These experiments and engineering studies are directed largely toward reducing vehicle weight and compliance with the Corporate Average Fuel Economy standards enacted by Congress.

Costs

Incorporation of the candidate alternate materials will in almost every case result in a vehicle cost increase. The direct material costs are the lowest with the existing material of construction, low carbon steel, and, of the suggested alternate materials, carbon (graphite) fiber reinforced plastic would result in the most expensive vehicle. The relative direct material costs are expected to remain at the same ratio in the future although carbon fiber prices could be reduced with increased production and aluminum prices may increase at a higher rate due to the intensive dependence on energy.

The direct labor costs to produce a vehicle are the lowest with low carbon steel and again are the highest for carbon fiber composites. Low carbon steel fabrication costs have the benefit of essentially sixty years of development. It is expected that the other materials will also benefit from an experience factor which will reduce but not eliminate the difference that is now found. Basic differences in properties would indicate that the candidate alternate materials will always be associated with a higher direct labor cost than low carbon steel.

9.0 CONCLUSIONS

1. Low carbon steel is and will remain the primary material of construction in future automotive structure based on the current cost projections. The use of HSLA steels will replace some applications of low carbon steel.

2. Vehicle first cost in dollars will increase, with the use of the candidate alternate materials.

3. Raw materials are available to permit the extensive application of aluminum alloys, HSLA steels, plastics, and glass or carbon fiber reinforced composites in future automotive structure.

4. Mill capacity is and will continue to remain marginal, on a supply-demand basis.

5. Vehicle durability comparable to that found with low carbon steel is achievable with the alternate materials with a weight reduction.

6. Crashworthiness, with reduced weight, can be maintained with alternate materials.

7. Front and rear end non-damageability can be improved with alternate materials, specifically elastomeric plastics, without a weight penalty.

8. Aluminum alloys and glass reinforced composites will continue to compete for hang on components. Aluminum alloys are more expensive but result in a greater weight reduction.

9. Plastics applications, as elastomeric materials, will increase for front and rear end non-damageable energy management up to 15 - 20 mph.

10. New process developments such as reaction injection molding (RIM) will increase plastics potential in exterior body panels where a combined weight reduction and cost effectiveness can be achieved.

11. New material developments in laminate or composite forms such as metal skin thermoplastic laminate and mixed fiber hybrid composites provide potential weight reductions at lower cost penalties, when combined with a steel space frame design.

10.0 RECOMMENDATIONS

Manufacturing Cost

Research and development effort should be continued or increased to reduce the manufacturing costs of applying alternate materials which will result in vehicle weight reduction. This includes simple detail programs as well as major efforts. Significant cost reductions could be achieved by:

a. Elimination of the cleaning costs and reduction of electrode costs during the resistance spot welding of aluminum alloys.

b. Reduction of the cycle time, and automatic press loading and unloading in the molding of fiber reinforced composites.

c. Development of automatic adhesive bonding of structural components at a rate comparable to resistance spot welding.

New manufacturing processes must be investigated to permit utilization of materials in a manner which exploits their best characteristics. The ability to press mold oriented fiber composites and obtain the desired orientation in the finished part would permit greater

utilization of their high strength and stiffness. Similarily the ability to join dissimilar metals at high rates and obtain highly efficient joints would increase the designers ability to use lower density materials.

Material Properties

Additional effort should be assigned to the determination of material properties to permit utilization of alternate materials within a shorter time span. The utilization of equipment and personnel outside of the automotive and materials industries, such as universities, to develop statistical materials design data would reduce the time needed before a material is actually used.

Analysis

An improved knowledge of operating loads imposed on the vehicle and faster methods of modeling and analysis would permit a finer tuned vehicle and an expected lower weight. Finite element methods of analysis have made significant gains in recent years and further improvements would enhance vehicle structure performance.

Conservation

Effort should be directed toward the reduction of energy and dollar costs to produce primary metal products. A reduction in the secondary energy carrier, such as electricity, to refine aluminum ore would benefit all industries. This may not be feasible although the ability to use natural occuring minerals or chemicals in the refining process would be of considerable usefulness. Improved recycling of scrap metals and organic materials in all discarded wastes is another approach to the reduction of material and energy costs.

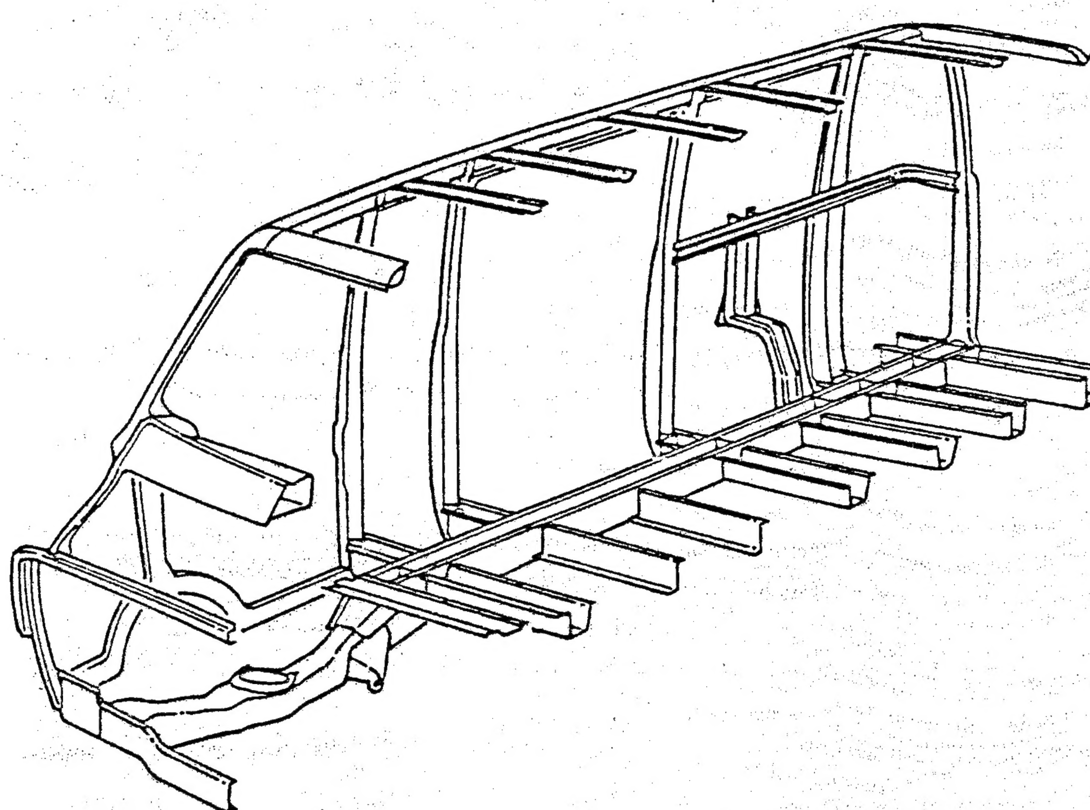
New Designs

New design concepts which will utilize existing material properties more fully should be sought. A particular design concept utilizing a steel space frame, Figure 4, with non structural closure panels, while not new, should be restudied in light of new low density aluminum alloys and plastic matrix materials, particularly for a van.

Crashworthiness

Tremendous progress has been obtained in the area of crashworthiness and safety and there is much more to be accomplished. Improvements in analysis and design techniques are required to reduce expensive test time and vehicle modifications which may not be beneficial to the passenger. A more complete knowledge of the energy absorption characteristics of alternate materials in vehicle configurations are required.

FIGURE 4 VAN-SPACE FRAME BODY



Health Hazard

Continuing investigations during the initial stages of material and manufacturing development must be maintained to identify and eliminate health hazards.